



Combustion features and use of space. A micromorphological approach to the Neolithic occupation at Cova de les Pixarelles (Barcelona, Spain)

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ABSTRACT

Combustion structures are a key element in archaeology for understanding the articulation of the social spaces of past societies since they allow us to approach domestic activities, given their role in daily life production and consumption practices. In the last years, the study of hearths and other combustion features has been enriched by applying a set of new methodologies, which has made it possible to delve deeper into its study and know both the activities involved in its use and the management.

In this article, we present the results of a micromorphological study carried out at the Cova de les Pixarelles site (Tavertet, Barcelona). The aim is to contribute to the knowledge of the use of space and rhythms of occupation of the Middle Neolithic societies in the northeast of the Iberian Peninsula by studying combustion structures and their management. The exceptional conservation of the remains in strata of highly organic composition due to the formation of travertine layers in the periods when the cave is not occupied constitutes this cave as a benchmark for occupations in karst cavities during recent prehistory in the region. More specifically, we will focus on Level XXII, consisting of a thick accumulation of ashes and faunal remains, among other utilitarian elements. Therefore, the ethnographic vision of the use of the cavity in the economic and social cycle is deepened by the first results of the micromorphological analysis and the rest of the archaeological record, which points to an intense occupation with several episodes of use related to several combustion features and changes in space management with possible specific purposes.

1. Introduction

Traditionally, the Middle Neolithic (4150–3500 BC) has been considered in the northeast of the Iberian Peninsula as a period of consolidation of the practices derived from the arrival of neolithic populations. Although neolithic communities in the northeast of the peninsula are well defined by the presence of intrinsically neolithic technologies and economic practices, the social changes that justify the transition from the Early Neolithic to the Middle Neolithic, however, still do not enjoy the same definition level.

On this matter, one of the most substantial changes that scholars

have highlighted concerns settlement patterns and modes of occupation in relation to the habitat (Martin 1985; Molist 1992; Tarrús et al. 1992; Molist et al. 2003). In this regard, there was a shift from a model based on open-air sites close to farmland complimented by occupation in caves used as storage places for agricultural products (Agustí et al. 1987; Bosch-Lloret et al. 1996), animal penning (Bergadà 1998; Bergadà et al. 2005; Oms et al. 2013) or burial (Bosch-Lloret and Tarrús 1990) to a dynamic of occupation of the territory in which both caves and shelters are abandoned, with exceptions such as Cova del Toll (Guilaine et al. 2020), Cova de Font del Molinot (Baldellou and Mestres 1977) or Les Grioterres (Castany 1995) only four km away from Cova de les Pixarelles.

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This fact highlights, in part, the singularity that surrounds the occupation of Cova de las Pixarelles.

Cova de les Pixarelles is a cave with multiple human occupations dating back to late prehistoric times that were sealed by the dynamics of the cave's formation. One of these occupations, Level XXII, is ascribed to the Middle Neolithic. The uniqueness of its occupation in its historical context, along with its richness in terms of archaeological remains (more specifically animal bones), and the stratigraphic complexity composed of superpositions of ashy layers and other combustion residues, led to the realisation of a micromorphological study to explore the functional history of the site through the formation processes of the archaeological deposits derived from combustion by-products.

The study of combustion features, understood as deposits or structures containing physical fire remnants (Mallol et al. 2017), can be approached from very different perspectives to obtain information on aspects such as fuels, management of natural resources, food and cooking practices, craft activities or even ritual practices (among others) as new interdisciplinary analytical techniques enable more contextual and high-resolution analyses of fire use and traces. Particularly, soil micromorphology has proven to be a suitable methodological technique. It allows simultaneous analysis of diverse organic, inorganic and microartefactual materials in situ within their depositional context and, thereby, permits accurate analysis of traces of fire. Indeed, this methodology enables a detailed interpretation of anthropogenic activities involving the combustion structure elaboration and maintenance, the ones related to the use of fire and those related to natural phenomena (Mallol et al. 2007, 2017; Goldberg et al. 2009; Berna et al. 2012; Huismán et al. 2012; Mentzer 2012; Shahack-Gross et al. 2014).

Specifically, this tool has been very useful in cave contexts, given the environmental particularities they present that contribute to the appearance of multiple diagenetic processes that directly affect the archaeological deposits (Wattez et al. 1990; Weiner et al. 1993; Karkanas et al. 1999, 2000; Shahack-Gross et al. 2008; Mallol et al. 2010; Karkanas and Golberg 2013).

In this light, this paper presents the results obtained from the micromorphological study of Level XXII at Cova de les Pixarelles. Due to the excellent conservation of the archaeological remains resulting from the stratification process of the cave, a unique case study is constituted from which the management and different uses of fire can be addressed. Furthermore, new insights will be provided on the use of space in the context of cave habitat and, in a broader sense, the dynamics and strategies of occupation concerning the economy and the functioning of Middle Neolithic societies of the northeast of the Iberian Peninsula.

2. Archaeological context: Cova de les Pixarelles site

Cova de les Pixarelles is located in the Collsacabra-Guilleries massif, specifically in the municipality of Tavertet (Barcelona) (Fig. 1a). It is placed at 670 m above sea level, close to the Riera de Balà, a tributary of the Ter River. The cavity has two entrances, yet only one is accessible at present. These are situated in an area with steep cornices and abrupt slopes that shape the valley through which the Riera de Balà flows (Fig. 1b).

Lithologically, the cave is located among the limestones and sandstones of marine origin formed during the Eocene, which are in unconformity with the sequence beneath formed by red oxidized rocks comprising lutites, sandstones and conglomerates of continental origin (see Fig. 1b) (Busquets et al. 1979; Álvarez 2001). This geological formation is divided into three units. At the bottom, where the cave is found, there are sandstones, bioclasts and oolites. The intermediate level comprises limestones, including foraminifera like nummulites and alveolina, while the uppermost layer displays an alternate of marl, sandstones and bioclasts units.

The cave is part of a complex karst system. Its stratigraphic sequence is formed by perfectly stratified sedimentation of tufa that originates from the combination of chemical and biological processes once the high

amount of calcium carbonate that the groundwater contains in solution precipitates. Water must remain stagnant in shallow deposits, or its circulation regime must be slow and smooth to facilitate its evaporation for the carbonates to settle. Regarding the nature of the cave's stratigraphy, it is mainly formed by a succession of extremely thin layers, likely to be identified as stromatolites. Its genesis is caused by the presence of cyanobacteria that are responsible for capturing and fixing carbonated particles. The formation of these layers of calcareous tufa is combined with thin strata, among which sediments with fine particles and greyish colours accumulate. Occasionally, these have been associated with periods of human occupation when appearing in darker tones. The appearance of these silty-clay units is explained by the cave dynamics, related to periods when it was probably not flooded. Therefore, the sequence that has been hitherto explored shows a cyclical alternation of well-stratified calcareous tufa units and layers formed by the input of fine materials that usually host the archaeological layers.

The site was surveyed for the first time in 1973 and excavated in 1974, 1983–1985 and 1988, when the work was paused and was not resumed until 2014. These first seasons confirmed the existence of a stratigraphic sequence defined by sixteen layers comprising many different occupations ranging from the Late Neolithic to the Late Bronze Age, with the sporadic presence of Roman and Late Medieval remains in the higher levels (Rauret 1982; Rauret 1987; Álvarez and Rauret 1996; Álvarez 2001). The findings proved that the complete stratigraphic sequence of Cova de les Pixarelles is complex and well-marked by periods of occupation and abandonment. The fact that all the levels with evidence of human activity appear sealed by calcareous concretions has allowed the hermetic closure of each one of the occupations. In this regard, the archaeological deposits do not appear altered by later occupations. As such, there have been no considerable modifications after the site's abandonment besides the erosive action of water.

In short, these previous works highlighted the recurrent and continuous human occupation of the cave. Since fieldworks resumed in 2014, a total of XXV levels have been documented so far. This fact denotes its importance in articulating and exploiting the territory due to its location and characteristics over time.

2.1. Archaeological context: Level XXII

Since 2014, fieldworks at the cave have been developed in the north end of the gallery, the farthest area from the entrance, and covering an area of 6 m² (3 × 2 m) divided into six squares of one metre each (Fig. 2). The surface presents a slope oriented from E to W, and from N to S. Then, throughout the stratification process, the upper layers progressively adapted their morphology to these slopes (Fig. 3).

Level XXII appeared during the fieldwork carried out in 2016. Throughout its excavation, a series of sedimentary facies were defined according to their colour, particle size, structure, and inclusions. At first, they seemed to indicate a specific occupation characterized by the accumulation of ashes, charcoals, a large number of faunal remains and some ceramics. However, the complexity of the stratigraphic superposition concerning the appearance of discontinuous tabular deposits led to the realization of the present study. Finally, radiocarbon dating on two samples place this occupation between 3930 and 3640 cal BC.

2.1.1. Archaeological remains

Among the material recovered in Level XXII, it is worth noting the presence of zooarchaeological remains with >1000 bone fragments (Fig. 4a and b). It is a large ensemble presenting excellent conditions of preservation where the significant presence of *Bos Taurus* (>85 %) stands out. The presence of goat/sheep fragments and occasionally suids is also confirmed. The analysis of skeletal parts per species shows a recurrence in the skeletal parts represented, with a particular focus on extremities, with juvenile and subadult male specimens being the most represented. Evidence shows that there is a specific priority for high return skeletal parts, although, in the case of cattle, ribs and cranial parts

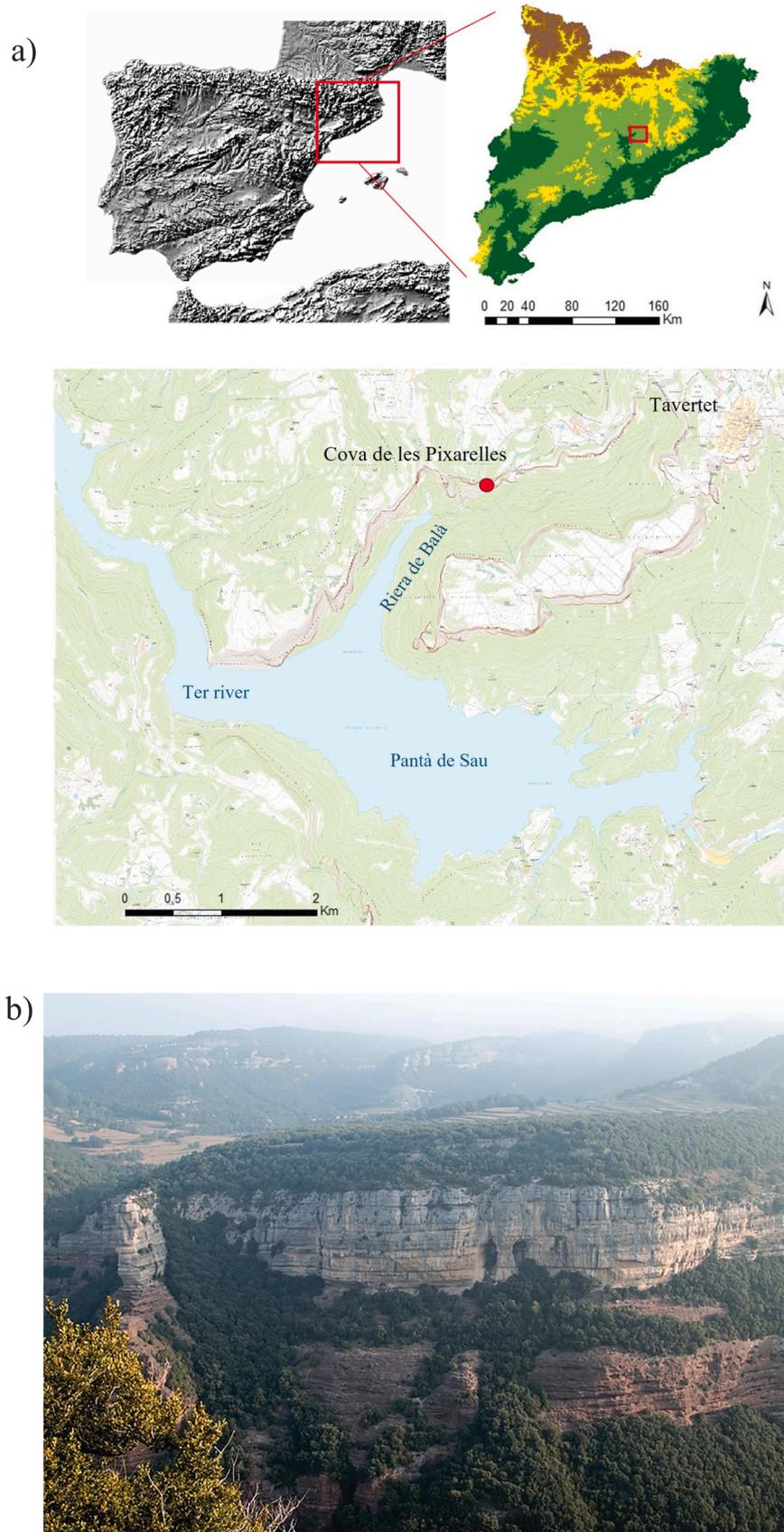


Fig. 1. Geographical location. a) Map showing the location of Cova de les Pixarelles (Tavertet, Barcelona, Spain). b) Situation of Cova de les Pixarelles.

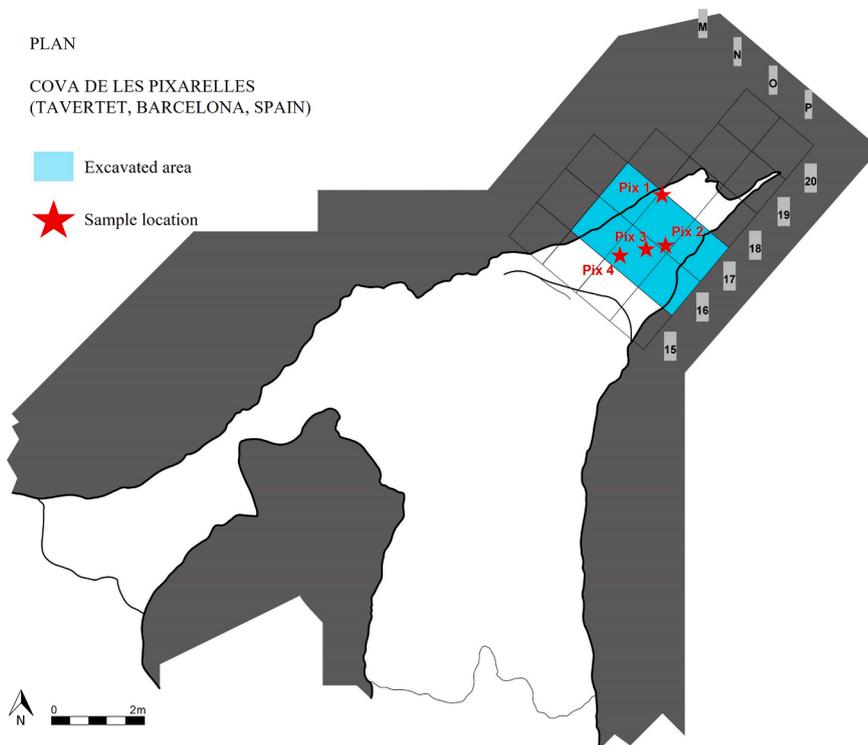


Fig. 2. Plan of Cova de les Pixarelles. Excavation area since 2014 and sample locations.

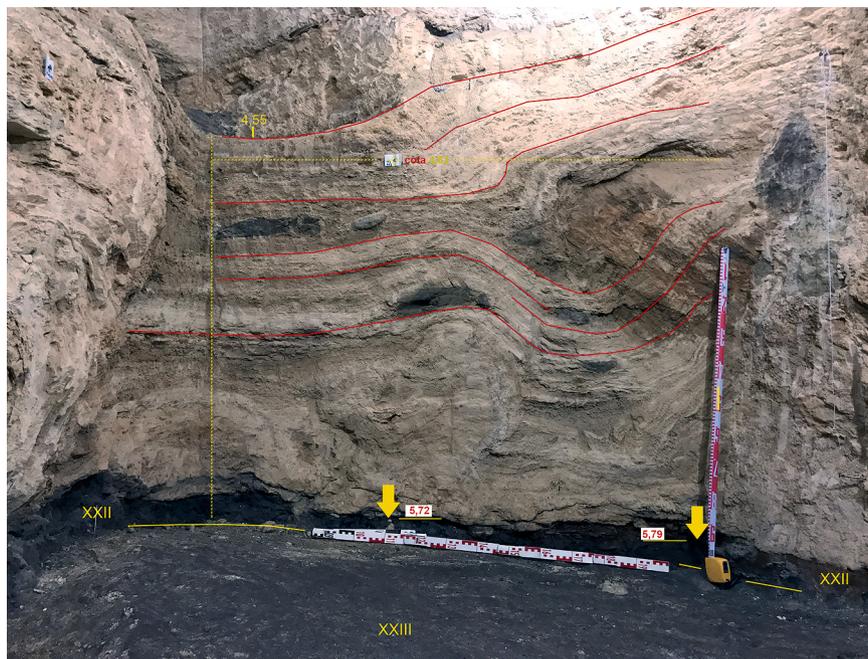


Fig. 3. West profile. Situation of Level XXII in section (facies C visible) and beginning of Level XXIII in plan.

are also well represented (Alcántara 2019; Molist et al. 2019). Some of them display apparent signs of intentional chopping and fragmentation and different degrees of thermal alteration according to their colours.

Pottery fragments are also commonly found. Although its fragmentation index is high, probably due to the high degree of humidity, the presence of a homogeneous set of small to medium-sized cooking pots and bowls stands out, manufactured with local raw materials. Its typologies and dimensions suggest a domestic-culinary use for food processing and liquid/food container (Álvarez 2019; Molist et al. 2019).

On the other hand, lithic materials are scarce. These flakes are made on white and pink quartz without retouching. These elements are local, most likely coming from pebbles embedded in the sedimentary formations near the site. Also, some quartzite rocks appear to be worked to get a shape suitable for percussion. Those are simple morphologies with low work investment that suggests a very punctual use (Álvarez 2019).

Among the remains resulting from the sediment flotation process, charcoal fragments, animal bone fragments, and small pottery fragments predominate, as well as charred remains of acorns.



Fig. 4. Accumulation of archaeological remains in Level XXII. a) Materials at the bottom of Level XXII - facies C. b) Archaeological remains embedded in facies B, facies B is still visible in the background on top.

Finally, the macroscopical evidence indicates that once this occupation was abandoned, no notable erosive phenomena occurred since the sediment does not show signs of post-depositional alterations apart from the shallow flooding, which contributed to the sealing by successive layers of calcareous tufa.

3. Materials and methods

Soil micromorphology has been conducted on sediments from Level XXII. In the field, it was described as a thick layer (25 – 35 cm) composed of grey clays highly altered by the presence of organic remains, small charcoal fragments and abundant ashes that conferred considerable chromatic variability. Consequently, the colours varied between greyish tones typical of strongly anthropogenic levels at the site, with sudden changes in hue that ranged from light grey to dark grey-black. Besides, their distribution varied, sometimes with diffuse limits. This fact motivated the distinction between three types of facies (from top to bottom): A, B and C, the description of which is presented in [Table 1](#).

3.1. Micromorphological analysis

The micromorphological analysis aims to study the formation dynamics of the archaeological deposit involving the nature, composition, depositional pathways, and post-depositional alterations of the occupational deposits characterised by the presence of combustion by-products as well as to approach the functional history of the occupation.

The micromorphological analysis has been performed on four thin sections prepared from four undisturbed block sediments comprising the three sedimentary facies identified in Level XXII (see [Table 1](#)). Samples Pix-1 and Pix-4 were collected from the northern profile of the O17 area and near the southern profile of the O16 area respectively, while Pix-2 and Pix-3 come from the northern section of O16, that is, the centre of the trench, to cover the greatest possible spatial variability according to the accumulation of the sedimentary record (see [Fig. 2](#) and [Fig. 5](#)).

Following oven-dried at ca. 40 °C, the sediment blocks were consolidated in the laboratory by impregnating them with a polystyrene resin and dried for several weeks. Then, 30 µm thin sections measuring 13,5 × 6,5 cm were produced. Microscopic analysis was realized on a petrographic microscope (x25 to x400 magnifications) under plane-polarized light (PPL), crossed polarized light (XPL) and oblique incident light (OIL). The descriptions followed published guidelines ([Bullock et al. 1985](#); [Courty et al. 1989](#); [Stoops et al. 2010](#); [Stoops 2021](#)).

The procedures for interpreting the microfacies employed in this research consisted of: (a) the qualitative and semiquantitative description of deposits within the sample group and their comparison considering their stratigraphic relationship; and (b) the comparison of description and interpretations to micromorphological studies of

Table 1
Summary of micromorphological samples and field observations.

Facies	Sample	Field description	Main issues
A	Pix-4	Layer formed by a massive and compacted whitish-light grey (N 7/ – N 8/) accumulation of ashes with few charred remains primarily located in the O16 and P16 areas. It is the uppermost layer of Level XXII and displays a variable thickness, which increased as it was closer to the southern profile.	To investigate the nature and composition of the ashy layer to approach the fire conditions, fuel sources and its functional history.
B	Pix-1/ Pix-3	Thick accumulation (10–12 cm) of olive yellow (5Y 6/6) silty sands conferring a granular structure and compacted with occasional reddened spots. Mainly found in the O16 and P16 areas next to the cave’s wall and slightly raised. Stratigraphically it is found between facies A and C. The contact between units is clear and sharp.	To explore the nature and origin of the deposit as well as its depositional pathways.
C	Pix-2	Layer build-up of discarded faunal remains and charred plant remains embedded in an organic-rich dark deposit (10YR 4/2) spread over the entire sector on top of Level XXIII composed of calcareous tufa and below facies B. Its thickness varied between 6 and 14 cm.	To study the origin and composition of the deposit to understand the possible uses related to the fire as well as possible fuel sources.

deposits from other archaeological, experimental and ethno-archaeological contexts.

4. Results

4.1. Microfacies classification

As noted throughout the fieldwork, three different sedimentary facies were macroscopically identified, of which a total of four microfacies have been microscopically differentiated ([Fig. 5](#) and [Table 2](#)). Most of the facies identified in the field are confirmed as such under the microscope; for that reason, the same denomination has been maintained. These microfacies have been determined following the criteria established by [Courty \(2001\)](#) based on lithological and textural properties,



Fig. 5. Level XXII during excavation showing sampling locations and displaying the sedimentary facies observed and related thin sections with microfacies (MF) identified. Pix-1 does not appear in this photograph as it comes from the north profile of N17.

Table 2

Summary of micromorphological attributes following deposit type. Classification of the frequencies according to Stoops 2003: ● ≤1%, ●● 2-5 %, ●●● 6-15 %, ●●●● 16-30 %, ●●●●● 31-50 %, ●●●●●● >50 %. Classification of the abundance of pedofeatures following Stoops 2003: + <2%, ++ 2-5 %, +++ 6-10 %, ++++ 11-20 %, +++++ >20 %. – 2 column.

Microfacies	Facies	Sample	Microstructure and Porosity	Groundmass	Mineral components	Anthropogenic components	Pedofeatures
A1	A	Pix-4	Massive and crumbPorosity (10 %): vughs and subhorizontal planes	C/f limit: 50 µm C/f ratio: 20/80 Calcitic crystallitic b-fabric Open porphyric related distribution	Quartz ● Bioclasts ●	Charcoals ●●● Calcitic ashes ●●●●●● Bones ● Burnt bones ●	Coatings of micritic calcite in voids ++ Phosphatic hypocoatings in voids + Recrystallization and cementation of ashes +
A2	A; C	Pix-3; Pix-4	Complex microstructure Porosity (25 %): elongated vughs, packing voids and planes	C/f limit: 50 µm C/f ratio: 35/65 Calcitic crystallitic b-fabric Porphyric related distribution	Quartz ● Bioclasts ●	Charcoals ●●● Calcitic ashes ●●●●●● Charred nut shells (acorn) ●● Bones ● Burnt bones ●● Pottery ●	Coatings of micritic calcite in voids + Phosphatic hypocoatings in voids + Recrystallization and cementation of ashes +
B	B	Pix-1; Pix-3	Granular Porosity (30 %): Complex packing voids and vughs	C/f limit: 50 µm C/f ratio: 75/25 Calcitic crystallitic b-fabric Enaulic related distribution	Quartz ●●●●●●● Calcite ●● Quartzarenite ●● Lutite ●● Bioclasts ●● Nummulites ●●	Charcoals ●●● Bones ●● Burnt bones ● Pottery ●●	Coatings of micritic calcite in voids ++ Phosphatic anorthic nodules + Dusty clay coatings around quartz grains ++ Fe impregnative nodules ++
C	C	Pix-2	Crumb Porosity (20 %): vughs, vesicles and planes	C/f limit: 50 µm C/f ratio: 70/30 Calcitic crystallitic b-fabric Porphyric related distribution	Quartz ●● Speleothems ●● Calcite ● Bioclasts ●	Charcoals ●●● Calcitic ashes ●●Charred nut shells (acorn) ●● Bones ●●●●●	Coatings of micritic calcite in voids + Phosphatic infillings and coatings in voids ++ Recrystallization of ashes ++ Organic staining coating around bones +

microstructure, components and postdepositional processes. These represent either a single formation process or a combination thereof. Therefore, it is possible to link sedimentary processes with properly anthropic phenomena. The essence of the definition of facies or microfacies is a distinct combination of sedimentary features and characteristics observed at a particular scale. Below, the main characteristics of each of these microfacies are described (Table 2 for detailed description).

4.1.1. Microfacies A1

Microfacies A1 has been identified in the upper half of facies A. It comprises a crumb and locally massive microstructure formed mainly by the presence of rhombic grains composed of micritic crystal aggregates

(Fig. 6a-b). These ashes are likely to derive from woody plants according to their morphologies (Wattez 1988; Canti 2003; Mentzer 2012), which is reinforced by the presence of banded charcoals horizontally oriented parallel to the surface, some of them microscopically identified in thin-sections as Quercus sp., Tilia sp. and Salicaceae. Occasionally, bone and heat-altered bone fragments around 400–500 °C following Villagran et al. (2017) can be observed. Taphonomical aspects of ash are also detected, such as recrystallization and cementation (Fig. 7a-b). Recrystallization of ashes occurs as platy aggregates embedded in the ashy groundmass, whereas cementation is observed through the appearance of massive calcitic crusts, probably caused by the high moisture conditions due to water circulation. Phosphates as yellow-orange hypo-coatings around voids in the groundmass are also observed (Fig. 7c-d). Their

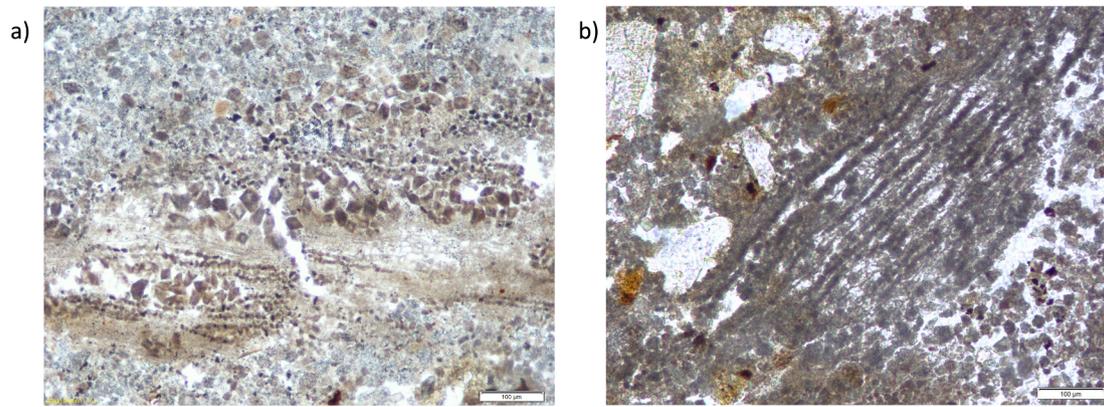


Fig. 6. Microphotographs of well-preserved ashes characterising microfacies A1 (a) displaying calcium carbonate pseudomorphs of prismatic crystals (b) often still articulated, PPL.

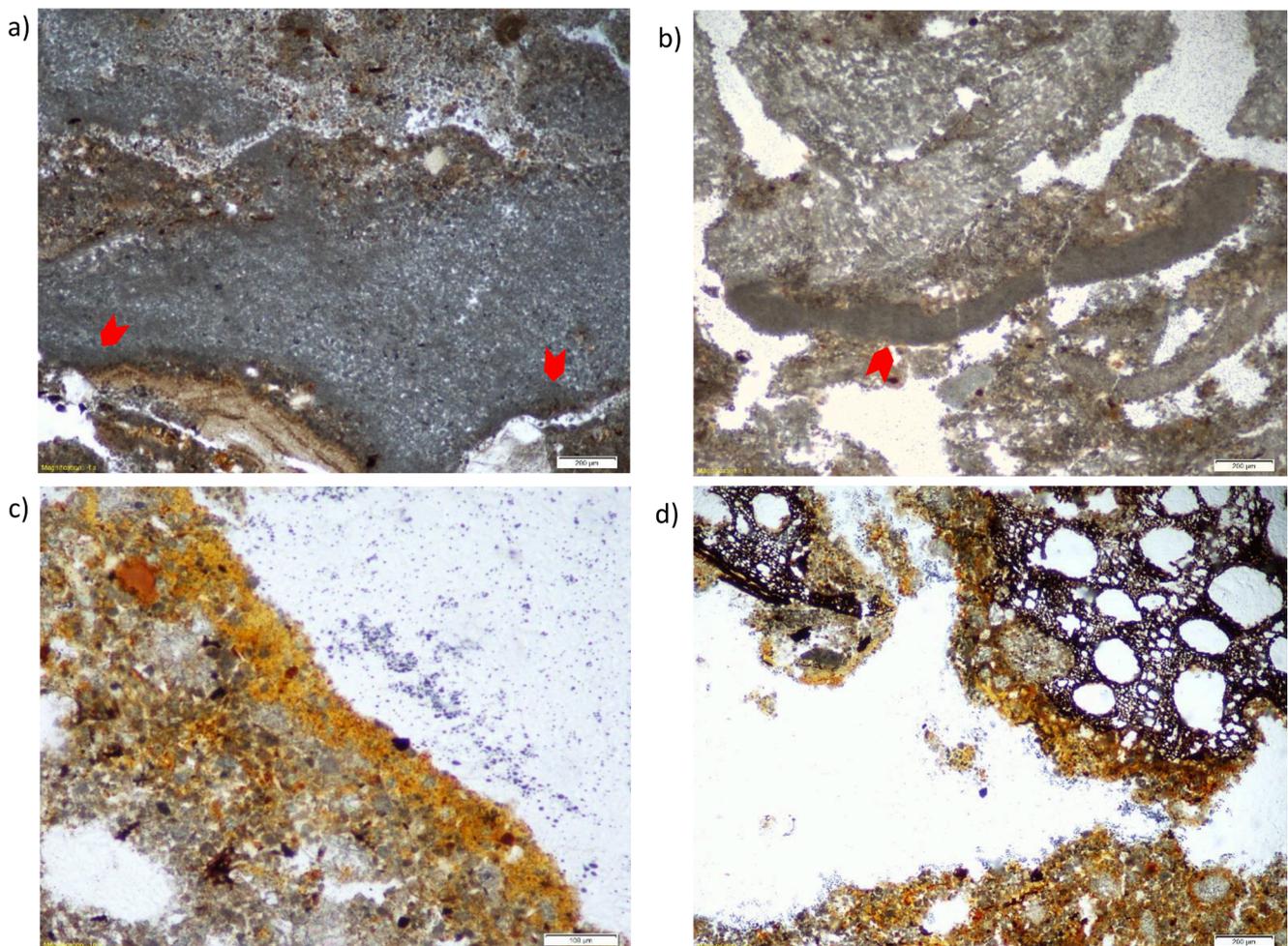


Fig. 7. Pedofeatures observed in microfacies A1 comprising ash recrystallization and cementation as well as phosphate precipitation. a) Ash aggregate showing recrystallization of ashes in the edges (arrows), PPL. b) Laminar crust of fully cemented and recrystallized ashes (arrow), PPL. c) Yellowish-orange phosphate hypocoating around voids, PPL. d) Yellowish-orange phosphate hypocoating around voids associated with charcoal, PPL. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

occurrence may be related to the appearance of phosphate sources, of which the unique susceptible element is wood ash (Wattez 1992; Thy et al., 1999; Weiner et al. 1995); otherwise, phosphatic input remains unknown.

4.1.2. Microfacies A2

Microfacies A2 constitutes a variation from microfacies A1 and has been identified in the lower half of facies A and the upper limit of facies C. This microfacies comprises similar components such as pseudomorphs of calcium carbonates, fissured fragments of centimetric charcoals, heat-altered bones ca. 300–400 °C as attested by their colours

(Villagran et al. 2017) and crack structures, and occasionally small pottery, but exhibits a reworked microstructure. The coarse components are embedded in the ashy matrix and parallel oriented with a certain degree of perpendicularity. Some of the charred plant remains are attributed to *Quercus* sp. Few phosphatic pedofeatures, including impregnations as yellow-orange hypocoatings around voids, are observed (see Fig. 7c-d). Other post-depositional features concern the recrystallisation and, to a lesser extent, the cementation of ashes caused by the percolation of water and evidenced by the loss of porosity, the aggregation of rhombic aggregates and the presence of massive calcite crusts (see Fig. 7a-b).

4.1.3. Microfacies B

Microfacies B relates to Facies B in the field. It is distinguished by an olive-yellow colour and is composed of coarse angular and subangular medium to very coarse sand-sized quartz, along with some fragments of foraminifera fossils such as nummulites. Microscopically it has been possible to recognize the presence of highly carbonated clays showing a calcitic crystallitic b-fabric. Its microstructure is granular with some microaggregates between grains, conferring mainly an enaulic related distribution. Among the anthropogenic components, some small fragments of bones, a few burnt at ca. 300–400 °C following the criteria established by Villagran et al. (2017), charred plants appear punctually and randomly distributed as well as pottery (Fig. 8a-b). The presence of a significant pottery fragment on its surface is also of note. It is also remarkable the presence of randomly distributed dusty clay coatings around the mineral grains, pointing to its inherited origin and, as such, suggesting the re-deposition of the sediments. In addition, micritic calcite coatings occur in minerals and voids caused by the circulation of CaCO₃ saturated water, a fact that entails the translation of fine particles from upper to lower layers (Durand et al. 2010) and contributes to the calcite cementation and recrystallization of the lower ashy layer. The circulation of water and temporary waterlogging is also noted owing to the appearance of iron oxides and hydroxides nodules within the groundmass and grains with oxidized clay coatings reddened to the naked eye (Fig. 9a-b). Phosphatic grains occurring under isotropic microcrystalline appearances are also present, which are encountered mainly at the base and in contact with the lower unit as small pale yellowish isolated nodules (<800 µm), suspected to be altered guano (Fig. 10a-b).

4.1.4. Microfacies C

Microfacies C is a dark grey layer of carbonated clays, few ashes, and fine to medium sands. Few remains of speleothems belonging to the natural sediments of the cave are also found. Its microstructure is crumbly and contains vughs, vesicles and some subhorizontal fissures, especially in contact with the bone fragments. The bones are undoubtedly the main component of this microfacies with measures exceeding 5

cm, linearly distributed and not oriented. Fragments of charcoals, some of which have been identified as *Quercus* sp. and semi-carbonized plant fragments also appear. The sporadic presence of charred nut shells is attested, likely to belong to acorns based on the recovered remains during flotation. As in other microfacies, micritic calcite coatings also appear, especially in voids. Regarding taphonomic processes, some charred plant fragments and bones appear coated by organic staining, caused by their degradation and possibly indicating the presence of flesh in bones when deposited (Villagran et al. 2017) (Fig. 11a), which evidence the high organic content of the deposit. Finally, phosphates in microfacies C are encountered as yellow cryptocrystalline infillings and coatings of voids (Fig. 11b-c). The only sources of phosphate precipitation might be wood ash (Wattez 1992; Thy et al., 1999; Weiner et al. 1995) or the degradation from organic matter; besides that, the phosphatic input is still unknown.

4.2. Interpretation of microfacies

The nature of the minerogenic elements of the different microfacies allowed differentiating between two groups. On the one hand, those components formed outside the cave and, on the other hand, those coming from inside the cave, containing speleothem fragments. The first group comprises microfacies B. It is formed by materials that somehow were introduced inside the cave by either natural or anthropic processes. The absence of distinguishable stratification, together with the chaotic, poorly sorted nature of the sediments within this microfacies, indicates that it was rapidly deposited in a single event, also suggested by the syndimentary porosity formed during the deposition of the sediments characterised by packing voids and vughs. This fact is reinforced by the sharp, smooth boundary established with the microfacies in contact, suggesting a sudden deposit formation. Furthermore, the fragmentation of inherited dusty clay coatings, randomly distributed around the grains, points to the re-deposition of the materials. Thereby, altogether is indicative of a debris flow or runoff deposit-type. Nevertheless, it is unlikely since it would imply a unique event that would change the percolating water regime of the cave, which has not been still documented again throughout the stratigraphy of the site as the natural stratification of the cave alternates the combination of percolating water, causing the formation of calcareous tufa, and layers of relict fine materials. Moreover, although low (5 %), the appearance of few anthropogenic materials embedded in the groundmass, such as charcoals, bones, and pottery fragments, would indicate an origin of the sediments from human-occupied areas. Therefore, overall, it suggests its deposition by anthropogenic agents, likely to derive from the cave's entrance, where colluvial sediments accumulate.

The mineral composition of the other microfacies is less varied and includes elements originating from inside the cave. However, the main difference between them is the percentage of the coarse fraction and the

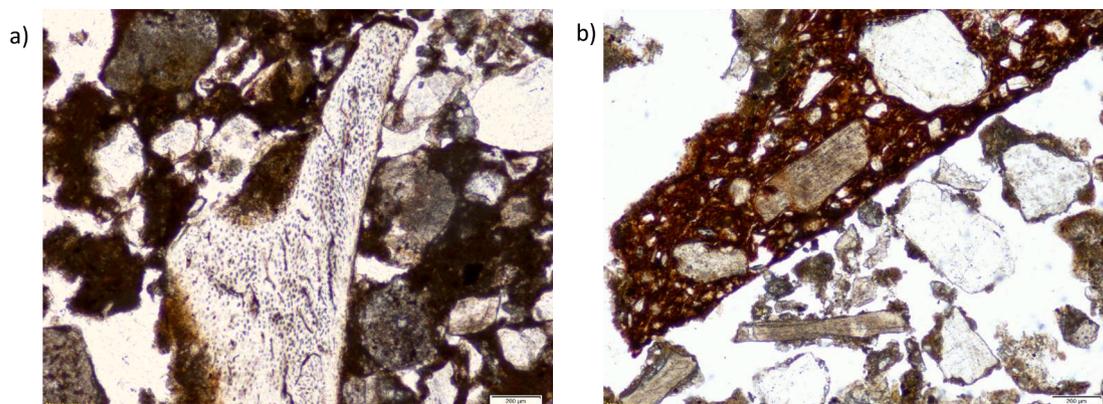


Fig. 8. Microphotographs of microfacies B showing anthropogenic materials found embedded in the groundmass such as bones (a) and pottery (b), all in PPL.

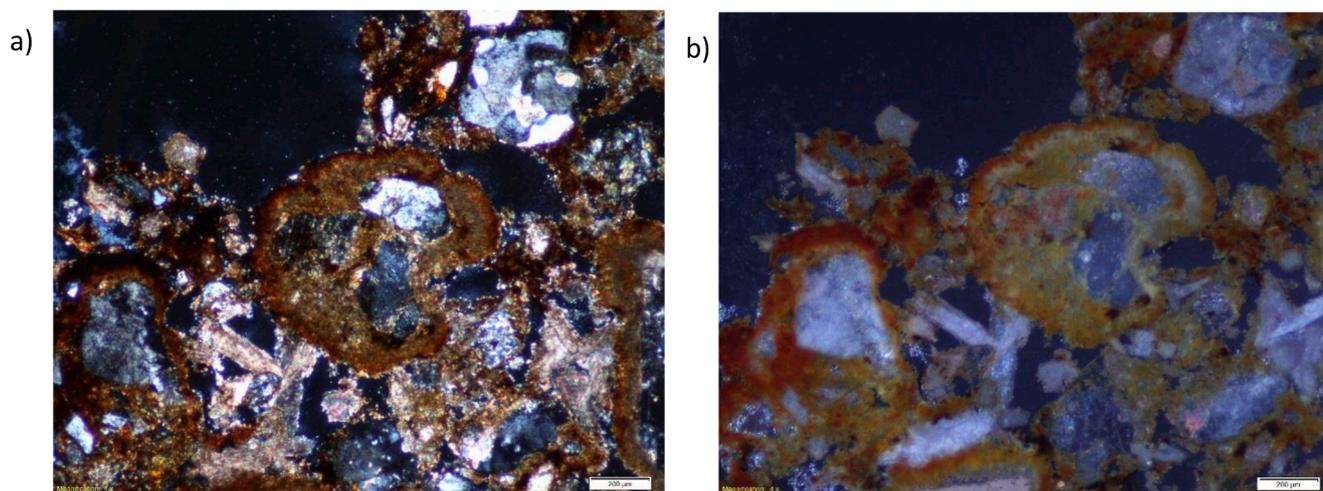


Fig. 9. Microphotograph of microfacies B showing oxidized coatings around grains caused by water in XPL (a) and OIL (b).

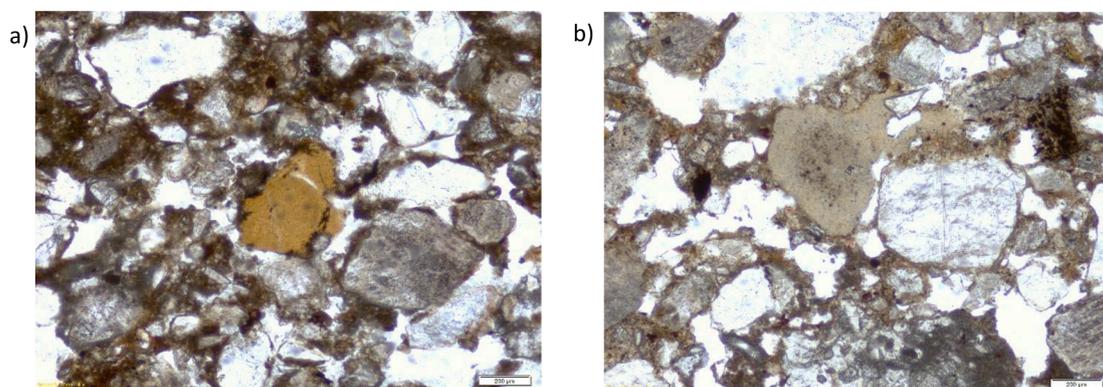


Fig. 10. a) and b). Microphotograph of pale yellow phosphatic microcrystalline grains found in microfacies B, PPL. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

porosity rates. While in microfacies A2 and C, the porosity is around 25 %, in the case of microfacies A1, it is approximately 10 %. This fact is due to its massive composition of ash-derived aggregates of pseudomorphs of calcium carbonate articulated and juxtaposed to the charcoal fragments. Such elements form from woody species and small branches used as fuel when reaching temperatures around 500 °C (Courtay 1984; Wattez 1988, 1992; Canti 2003). The presence of articulated ashes and partially carbonised tissues, together with the wavy internal fabric of certain ash lenses, suggests its deposition and burning in situ (Karkanas et al. 2007; Mentzer 2012). Moreover, this deposit is likely to result from complete and long combustion under oxidising conditions since coal is sparse in proportion to the amount of ash (Mentzer 2012).

As above-mentioned, microfacies A2 constitutes a variation of A1, where the main difference concerns the microstructure and the distribution and orientation of the inclusions. While microfacies A1 represent a layer of in situ combustion, microfacies A2 is interpreted as displaced fuel source materials according to their distribution likely to be sorted by gravity, their fracturing, the absence of articulated ashes and the higher porosity containing mostly vughs and packing voids. The occurrence of this microfacies is associated with microfacies A1 and C.

Microfacies C differs from the rest mainly by the presence of significant bone fragments and the prominent appearance of charcoal fragments dispersed on the surface. Its attributes indicate this is a reworked deposit derived from the rake-out of the fire-related activities residues and fuel sources before the fuel's complete combustion since sediments appear enriched by charcoal in relation to ash (Homsey and Capo, 2006; Meignen et al., 2007). In addition, it is noteworthy that the substrate

layer shows no evidence of reddening; therefore, the combustion structure was placed somewhere near the entrance.

Finally, post-depositional features identified microscopically, such as the oxidation of the sediments and the precipitation of micritic calcite (microfacies B), are consistent with the dynamics of the natural stratification process of the cave, which concern the circulation of water containing calcium carbonates. Subsequently, this led to the cementation and recrystallisation of ashes in the ashy layers (microfacies A1, A2 and C), contributing to the reduction and compaction of the volume of ashes. These features allow approaching the knowledge of the local environment inside the cavity, characterised by a high degree of moisture, which, in turn, could increase the appearance of diagenetic processes involving the degradation of organic matter (Fig. 12a-b) and the precipitation of the observed phosphatic pedofeatures in most of the units. These phosphates have been identified in numerous cave deposits (Goldberg 2001). Their appearance and the deposit conditions suggest it is likely to be dahllite, a calcium phosphate mineral derived from apatite, although further analyses are required to confirm that. Its formation is related to different factors depending on the characteristics of the environment. Among these, the most likely is the release of phosphates that occurs when organic matter derived from bat or bird droppings is oxidised and appears associated with periods of non-occupation (Wattez and Courtay 1987; Karkanas et al. 1999, 2000; Karkanas and Goldberg 2010). In addition, the wood ash itself can also be a formation source since it can contain up to 24 % phosphates (Wattez and Courtay 1987; Thy et al., 1999) in the same way that the dissolution of the bones can also be (Karkanas et al. 2000) in environments conducive to the

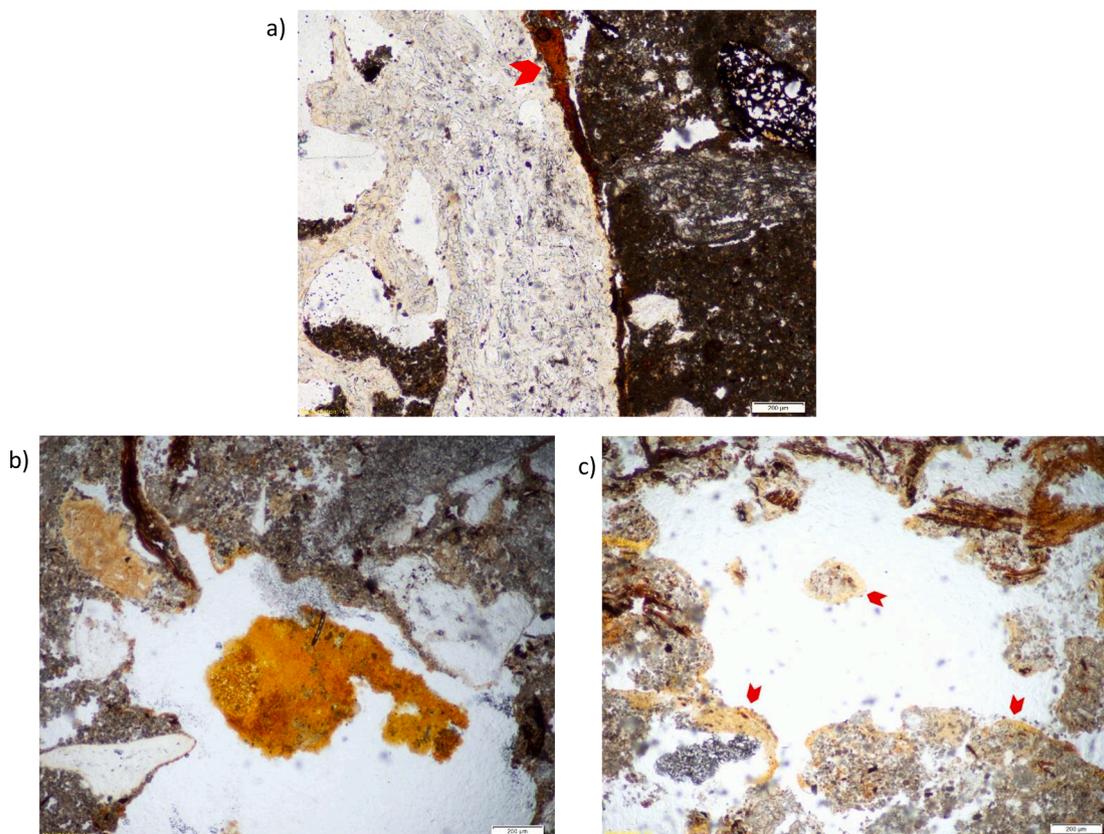


Fig. 11. Microphotographs of post-depositional features observed in microfacies C. a) Organic staining coating a bone fragment likely to form after decayed organic matter, PPL. b) Yellow-orange cryptocrystalline phosphate infilling in void, PPL. c) Pale yellow phosphates coating voids (arrows), PPL. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

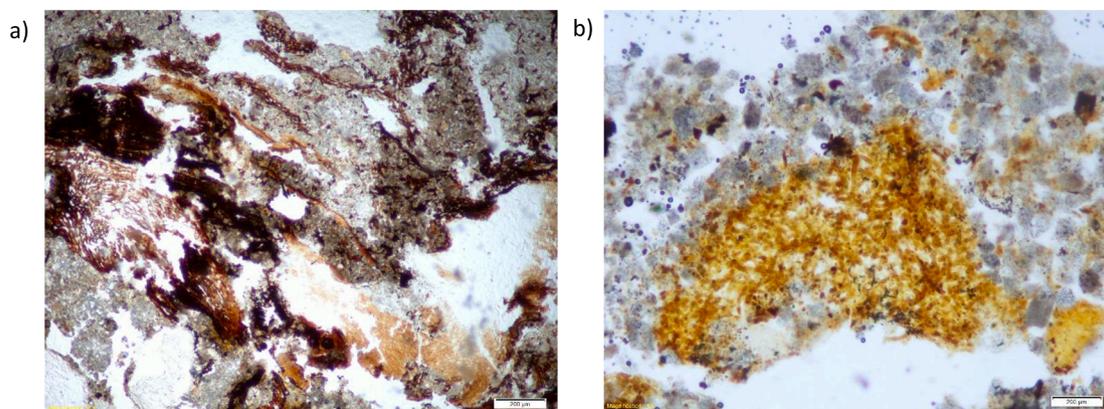


Fig. 12. Microphotographs showing (a) decayed charred plant remains in microfacies C and (b) decayed organic matter in microfacies A2, all in PPL.

appearance of physicochemical processes such as caves.

At Cova de les Pixarelles, phosphates have been identified in thin sections from all the facies described in the field. These occur as authigenic nodules concentrated at the base of microfacies B, presumed to be altered guano, and as hypocoatings and infillings in voids of microfacies A1, A2 and C. The fact that these are not primary minerals but the result of precipitation processes is indicative of the presence of phosphate sources. In the microfacies rich in ashes (microfacies A1 and A2), phosphates could be originated from the calcite component of wood ash, a diagenetic process well attested in cave contexts (Wattez 1992; Weiner et al. 1995). In the case of microfacies B, the grains observed at the base in the transition with the lower unit might result from decayed organic matter possibly deriving from guano that could be deposited on the

surface of the unit below. An alternative, but non-excluding hypothesis, is that phosphatic nodules could be inherited, therefore indicating the sediments at some point were placed near the cave entrance before their deposition, and consequently reinforcing the supposition about their re-deposition from the entry of the cave or its immediate surroundings. Rather than that, other different sources of organic matter are unknown. Finally, phosphate coatings and infillings in microfacies C could hypothetically result from the dissolution and reprecipitation of phosphates from the upper layers or the high content of organic matter, as shown by the degraded charred plant remains and coatings of bones.

5. Discussion

Within the geographical and chronological framework, the example of the Cova de les Pixarelles constitutes an exception in a context where occupations in open-air settlements prevail while habitats in caves are scarce. Based on thin section analyses presented above and in combination with the macroscopic observations in the field, it has been possible to establish multiple episodes of use of the cavity according to different depositional events (Fig. 13).

The first episode documented in level XXII comprises facies C, formed by two microfacies (from bottom to top): microfacies C and A2. Microfacies C corresponds to an accumulation of discarded materials comprising an extraordinary assemblage of faunal remains along with combustion debris. The nature and abundance of the components suggest the performance of activities related to the processing and consumption of meat, as indicated by the presence of the high-return skeletal parts. The fact that most bones do not appear burnt, ash is almost absent and partially carbonised plant tissues appear together with charred remains suggests that the fire was interrupted (Braadbart and Poole, 2008; Mentzer 2012), as it was probably intended for cooking food and therefore was not maintained. The high organic content of this microfacies is evidenced by the presence of degraded remains of charred plant remains and bones coated by organic staining. Although no direct evidence has been detected so far, it is possible that, given the environmental conditions of the cave as well as the characteristics and quantity of animal portions, food preservation practices such as smoking meat could have been carried out to preserve a meat surplus in a protected place.

On top of it, there is microfacies A2, only detected at the microscopic level. The clear boundary between units would indicate a re-deposited rake-out related to another event of combustion constituted by fuel remains from a hearth located in the unexcavated area near the cave's entrance.

Upper in the sequence, facies B (corresponding to microfacies B) is distinguished by the deposition of allochthonous materials. In case phosphatic grains identified at the base in the transitional boundary with the unit below derive from decayed guano, it could imply a brief period of non-occupation before the deposition of microfacies B. However, a more extensive sampling covering a larger surface is needed to confirm that. According to its micromorphological attributes and context, it is difficult to consider whether natural agents contributed to its deposition following the stratification dynamics of the cave,

determined by the formation of calcareous tufa and the input of fine materials, which generally host the archaeological layers. Besides, the presence of anthropic materials in the groundmass indicates an origin from occupied areas, probably near the cave's entrance where detrital materials accumulate. Although its purpose remains unknown (i.e., clearance activities in the entrance, prepared hearth floor, etc.), it is possible to infer its use as an occupation surface as indicated by the archaeological remains on top of it together with the subsequent occurrence of facies A, which further implies a change in the use and management of the space regarding the previous deposits.

Also of note is the identification of microfacies B in sample Pix-1 located in the northern profile of the O17 area, which has been only identified through thin-section examination. The appearance of this isolated lens sharing the same characteristics as facies B, found in the P16 and O16 area, might suggest other episodes of accumulation of re-deposited materials.

The last facies identified in the field, facies A, has been microscopically divided into microfacies A2 and A1. These reflect a new change in the use of space, as the first deposit (microfacies A2) consists of another event of re-deposition of combustion debris constituted by reworked fuel sources such as charred plant remains and calcitic ashes. Following its micromorphological attributes, it seems to represent a single depositional event of hearth discards probably located near the entrance. The succeeding microfacies (A1) consists of a thick deposit build-up of articulated ashes likely to be formed in situ and some charred plant remains banded and horizontally oriented. The massive accumulations of calcitic pseudomorphs indicate intense and complete combustion under oxidising conditions, probably maintained. Indeed, this deposit could presumably correspond to a new utilisation of the same combustion structure indicating the continuous use of fires. Lastly, it is impossible to attribute a specific functionality to the use of the fires beyond its properties in cave contexts, such as lighting, food processing and consumption, hygiene, or smoking meat, among others considering the archaeological record.

Finally, some remarks can be established about the plant remains. The identification of taxa such as *Quercus* sp., *Tilia* sp. or *Salicaceae* fit with the site's environment and are still visible today in the landscape (Sanglas i Puigferrer 2008; Álvarez 2019). Accordingly, the fuel sources come from the immediate territory. Another fact to highlight is the absence of phytoliths in thin sections, which could be a consequence of the chemical alterations occurring inside the cave. Indeed, calcitic environments contribute to the sediments' alkaline conditions, which alter

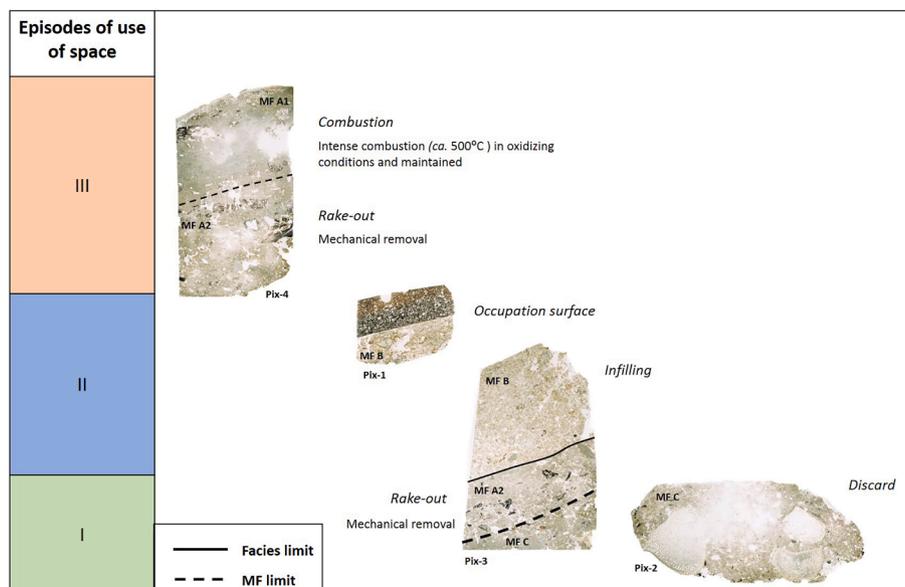


Fig. 13. Microstratigraphy of Level XXII and use episodes.

silica's preservation. The formation of calcareous tufa inside the cave denotes a high pH as it involves the deposition of calcite induced by the precipitation of water rich in calcium carbonates, which in turn creates a chemical environment conducive to preserving calcitic ash (Weiner et al. 2002). Moreover, the appearance of high concentrations of wood ash increases the pH due to the presence of alkaline hydroxides and carbonates (Wattez and Courty 1987; Ulery et al., 1993; Canti 2003). Considering that phytoliths dissolve in a pH > 8.2 (Weiner 2010), it is likely that the calcitic environment inside the cave promoted their dissolution and, at the same time, contributed to the preservation of calcitic ashes, which usually dissolve in acidic environments in a pH < 6.5 (Weiner et al. 2002; Canti 2003). Another cause explaining the absence of phytoliths might be related to the major use of woody plants as fuel, as indicated by the high concentrations of wood ash along with the presence of woody charcoals, which produce fewer phytoliths compared to non-woody plants (Tsartsidou et al. 2007).

6. Conclusions

Micromorphological analyses allowed us to delve deeper into the characterisation of the sedimentary facies recognised in the field. Indeed, the microstratigraphic approach has proven to be useful in determining the pre-depositional and depositional histories involved in Level XXII formation and assessing post-depositional processes that otherwise could not have been detected. Therefore, the importance of integrating soil micromorphology should be noted since it permits a detailed analysis of the stratigraphy and evaluates the natural and anthropic processes involved in deposit formation to approach the biogeography of social spaces.

The obtained results point to an intense cavity occupation that contrasts with the absence of cave occupations during the Middle Neolithic in the northeast of the Iberian Peninsula, except for the cases of Cova del Toll and Cova de Font del Molinot. The recovery of charred acorns has enabled to establish the hypothesis that the cave was occupied from October to January (when the acorns ripen). However, they can remain on the ground for long periods, thereupon could have been incorporated into the cave with the branches of *Quercus* sp. used as fuel or as edible fruit.

Although these occupations might have a seasonal nature due to the dynamics of the cave stratification, an intense occupation can be deduced from the multiple depositional events observed in thin-sections. It is impossible to ascertain if these consist of one or several occupations over time. However, whatever the case may be, its continued use based on the detected record, mainly linked to the presence of several combustion by-products depositional events, is ascertained.

Microstratigraphic observations allowed inferring issues about fire management. In facies C fire seems to be primarily linked to culinary practices and consumption, as suggested by the incomplete combustion of the hearth, together with the faunal remains and the set of tools recovered, even though its functional attribution is difficult considering its secondary position, then requiring extending the excavation surface to identified other possible features related. The enormous quantity of meat suggests an episode of consumption by a large community, which is challenging to attribute to the domestic sphere. On the contrary, facies A shows continued use of fire, with associated rake-outs probably linked to its maintenance, displaying signals of high-intensity combustion that could possibly be related to various functionalities such as lighting, cooking, hygiene, or smoking meat.

It is interesting to note the dominance established by the *Bos Taurus* specimen over the rest of the faunal assemblage, as well as the skeletal parts that constitute the record from a socio-economic perspective in connection with the articulation of the territory. This would respond to a specialised economic model in livestock by a group settled in the area where grazing and livestock management was achieved through a particular strategy well adapted to their environment (Alcántara 2019).

Finally, future work on the territory and the expansion of the

excavation area will enable the understanding of the human-landscape relation and compare it with the presence of open-air settlements to approach the strategies adopted by the communities that inhabited this area, evidence that is being verified for more recent chronologies.

CRedit authorship contribution statement

Joaquim Sisa-López de Pablo: Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing. **Julia Wattez:** Conceptualization, Methodology, Writing – review & editing. **Ramón Álvarez:** Conceptualization, Resources, Writing – review & editing. **Anna Gómez:** Conceptualization, Resources, Writing – review & editing. **Miquel Molist:** Conceptualization, Resources, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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